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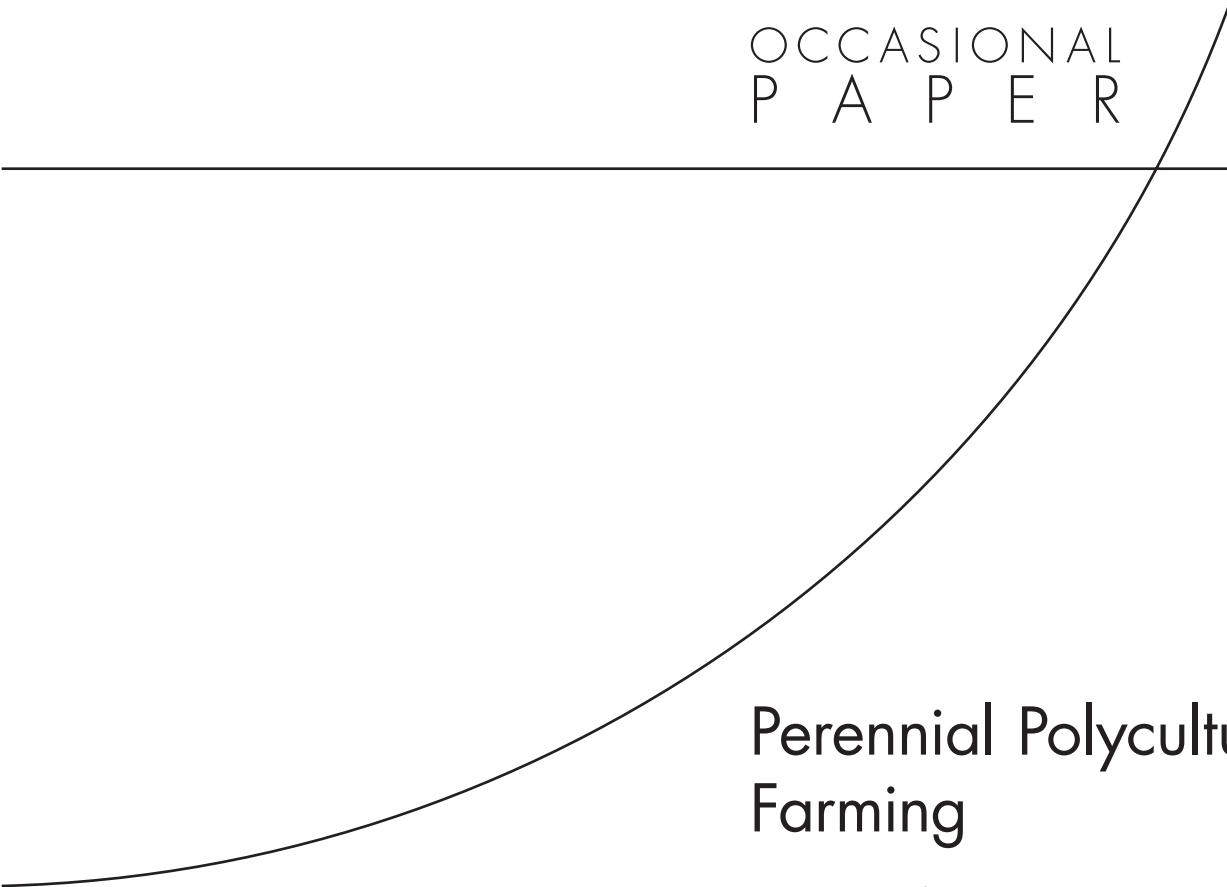
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# Perennial Polyculture Farming

## Seeds of Another Agricultural Revolution?

James A. Dewar



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This research was undertaken as a piece of speculation in the RAND Frederick S. Pardee Center for Longer Range Global Policy and the Future Human Condition with funding from the endowment for the center.

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## Preface

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The Green Revolution that was launched in 1943 in Mexico was a particular boon to developing countries because of the increases it afforded in agricultural production. Sixty-four years later, the Green Revolution technologies are still going strong in terms of agricultural production, but we are discovering that there was a price to pay in terms of, among other things, environmental degradation, erosion, soil degradation, water depletion and contamination, and a loss of biodiversity.

This research was undertaken as a piece of speculation in the RAND Frederick S. Pardee Center for Longer Range Global Policy and the Future Human Condition, a center of the RAND Corporation. Funding came from the endowment for the center. This paper is geared toward researchers interested in the longer-range future of agriculture and may also engage those interested in the longer-range future of the Earth.

### About the RAND Pardee Center

The RAND Frederick S. Pardee Center for Longer Range Global Policy and the Future Human Condition was established in 2001 through a gift from Frederick S. Pardee. The RAND Pardee Center seeks to enhance the overall future quality and condition of human life by improving longer-range global policy and long-term policy analysis. In carrying out this mission, the center concentrates on five broad areas:

- Developing new methodologies, or refining existing ones, to improve thinking about the long-range effects of policy options.
- Developing improved measures of human progress on a global scale.
- Identifying policy issues with important implications for the long-term future—35 years and beyond.
- Using longer-range policy analysis and measures of global progress to improve near-term decisions that have long-term effects.
- Collaborating with like-minded institutions and colleagues, including international organizations, academic research centers, futures societies, and individuals around the globe.

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# Perennial Polyculture Farming: Seeds of Another Agricultural Revolution?

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Humanity today faces a variety of problems on a global scale. These problems include poverty and hunger, growing worries about fossil fuel consumption, environmental degradation, loss of biodiversity, health problems—particularly among women and children—and a growing global disparity in education levels.<sup>1</sup> There is no shortage of solutions proposed for each of these problems, but there is one solution—perennial polyculture farming—that could contribute answers to *each* of these problems and deserves more attention than it has received. This extended opinion piece argues for the promise of perennial polyculture farming as a positive contribution to a wide variety of global problems and suggests actions that should be taken to explore that promise further. The format will be a series of questions and answers about perennial polyculture farming:

- What is perennial polyculture farming?
- What makes perennial polycultures different?
- What is the primary promise of perennial polyculture farming?
- What are possible secondary benefits?
- Is perennial polyculture farming truly feasible?
- Where should we go from here?

## What Is Perennial Polyculture Farming?

Much of agriculture today centers on annual plantings and harvestings of a single species over an extended area. Think of the wheat fields of Kansas with a single variety of wheat filling acre upon acre of the landscape. Perennials, as opposed to annuals, produce flowers and seeds more than once in their lifetime. In practical terms, perennials do not have to be planted annually. Perennial is a term usually applied to herbaceous plants or small shrubs rather than large shrubs or trees, but, in the strict sense used here, it applies to all plants that flower and produce

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<sup>1</sup> See Bjorn Lomborg, ed., *Global Crises, Global Solutions*, Cambridge University Press, Cambridge, 2004, for one listing of global problems.

seeds more than once. In some definitions, perennials are plants that last three or more seasons. For our purposes here, the longer, the better.

Polycultures are a bit harder to pin down. The classic wheat fields of Kansas represent a monoculture—the planting of a single species of plant on a given plot of land. Technically, a polyculture is one in which more than one plant species is planted on a plot of land in a given year. This opens up a variety of possibilities that can be divided into two main groups: *sequential cropping* and *intercropping*. Sequential cropping occurs when two or more varieties are planted on a given plot of land during the same year. This is polyculture that overlaps in space, but not in time. In some regions, sequential cropping can produce four crops a year.

Intercropping occurs when two or more varieties are growing at the same time on a given plot of land. This is polyculture that overlaps in time *and* space, which permits a wide variety of designs. In time, two or more cultures can be planted simultaneously or separately (sometimes called *relay intercropping*). In space, there are even more possibilities. Common spatial polycultures include *row intercropping* (where separate crops are in separate rows), *strip intercropping* (where crops are separated into wider strips of rows), and *mixed intercropping* (where two or more crops grow with no distinct row arrangement).

The number of cultures can vary as well. In Mexico, it is common to plant maize, beans, and squash on the same plot of land. Many backyard gardens contain a dozen or more “crops” on one plot of land. Polycultures in some parts of the world can easily reach 30 and more species on a given plot of land. Polycultures technically include even noncrop elements such as trees<sup>2</sup> (which are perennials), and nonplant elements such as livestock and fish, but this is straying too far afield from our topic here.

## What Makes Perennial Polycultures Different?

Many of the fruits and nuts we eat come from perennial plants and trees. Further, polycultures are common in modern industrial farming and particularly common in small, subsistence agriculture around the world. Farmers have even combined perennial crops (usually trees) with annual polycultures. In virtually all cases, however, there is a period during which there is, at best, only partial ground cover. Perennial polycultures with mixed intercropping have continual ground cover throughout the year. As will be discussed below, that is an important difference.

The biggest difference, however, comes from considering perennial cereals. Most of the cereals that people eat (such as wheat, rice, oats, and corn/maize) are grown in annual plantings and often in monocultures. Since cereals account for at least half of dietary energy worldwide,<sup>3</sup> converting that production to perennial polycultures with mixed intercropping would be a significant change in worldwide agriculture.

<sup>2</sup> In fact, polyculture including trees (called agroforestry) is often identified as one of the most promising approaches to sustainable agriculture and is widely used in some parts of the world.

<sup>3</sup> World Health Organization, *Diet, Nutrition and the Prevention of Chronic Diseases*, WHO, Geneva, 2003, p. 16, Figure 1.

Said another way, had the first inhabitants of the prairies found that there were enough edible grasses there for their needs, they would not have needed to become annual tillers and sowers. They could have survived simply by reaping what they needed from the prairie year after year. Indeed, when human populations were smaller, many societies did subsist on what wild ecosystems provided. Prairie ecosystems—with their perennial polycultures and mixed intercropping—required no maintenance, yet provided food for a variety of animals, continuous ground cover and deep root systems to prevent erosion, legumes to provide natural fertilizers, and natural disease and pest control measures. Thus, if we could engineer more bountiful prairies, we could dispense with much of the machinery, energy, fertilizers, irrigation, herbicides, and pesticides that are mainstays of modern agriculture. That, in turn, would have secondary benefits in environmental remediation, biodiversity, energy use, and—as I will argue below—in combating global problems such as poverty, hunger, and even disparities in education.

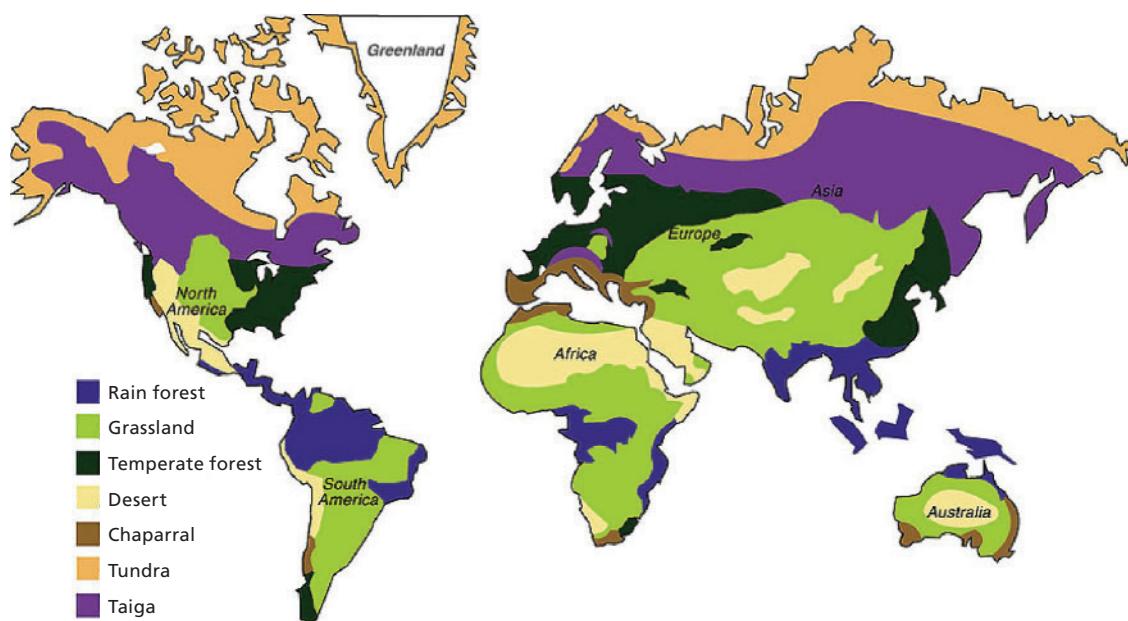
For the purpose of the speculations in this paper, it is useful to carry a single image of a perennial polyculture. For that image, return to Kansas. Polycultures are well known to be beneficial in modern agriculture, but there is a wide variety of polycultures. *The type of polyculture of interest in this paper consists of perennial plant species with mixed intercropping.* Historically, the Kansas prairies could be described as perennial polycultures with mixed intercropping. These prairies supplied food for a large variety of animal life, but when humans came, they chose to replace the prairie grasses with their own crops. Think of perennial polyculture farming as a reengineering of the prairie and its mixed intercropping to support human life on a large scale. That is, think of a prairie that looks and behaves similar to the prairies before humans arrived, but one that is engineered to produce food for humans and that rivals the productivity of modern industrial agriculture. This kind of agriculture forms the starker extreme compared with the annual industrial monoculture approach of today and is a useful image to carry through the arguments that follow. The image of a Kansas prairie polyculture emphasizes grains over vegetables, nuts, and fruits, but only for purposes of exposition. True perennial polyculture agriculture would include vegetables, nuts, and fruits, as well as grains.

Before moving on, it is important to note that the potential benefits of reengineered perennial polycultures are not restricted to the prairies of Kansas. Natural perennial polycultures can be found in all the world's grasslands and in other ecosystems as well. If these natural perennial polycultures could be reengineered to provide food on a large scale, the potential benefits could have global impact. To give a feel for the fraction of the world's landmass that might be a candidate for some type of perennial polyculture, Figure 1 presents a rendering of the world's biomes.<sup>4</sup> Perennial polycultures are plausible in the areas of rain forest, temperate forest, grassland, and chaparral in Figure 1. This covers virtually all of the world's land currently under significant cultivation (see Figure 2).

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<sup>4</sup> There are arguments over exactly what constitutes a biome and what the boundaries of the various biomes are. In Figure 1, a biome is the same as an ecosystem and is defined at the University Corporation for Atmospheric Research Web site as “a region of land [with] its own unique climate and life.” This definition and the map in Figure 1 are fairly representative of the Earth's ecosystems or biomes.

**Figure 1**  
**A Map of the World's Biomes**



SOURCE: The source of this image is *Windows to the Universe*, of the University Corporation for Atmospheric Research. Copyright ©2004 University Corporation for Atmospheric Research. All rights reserved. Used with permission. As of April 13, 2007:

[http://www.windows.ucar.edu/tour/link=/earth/images/biomes\\_map\\_big.jpg\\_image.html](http://www.windows.ucar.edu/tour/link=/earth/images/biomes_map_big.jpg_image.html).

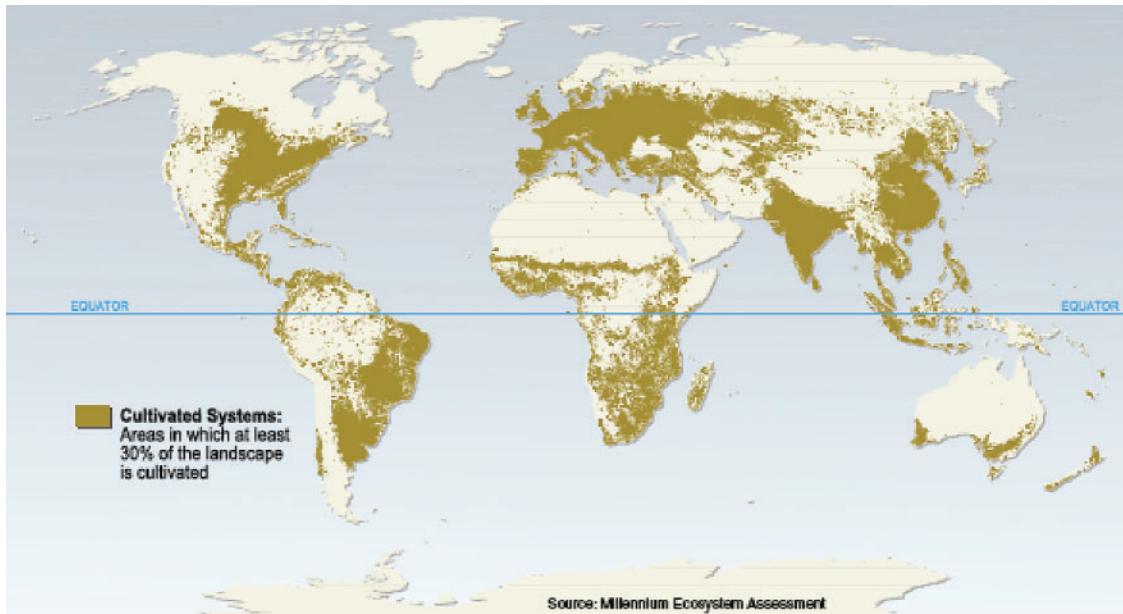
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Developing crop-yielding perennial polycultures in a given region of the world requires careful attention to the specific combination of perennials that will work best in that region. The practical problems involved in developing perennial polycultures are legion and idiosyncratic to a given area and bring up such fundamental questions as whether native plants should be reengineered or nonnative species should be introduced. But this is a work of speculation about the longer-range future, so for the time being, presume that some kind of perennial polyculture farming is at least plausible across the world's grassland, temperate forest, chaparral, and rain forest biomes.

## What Is the Primary Promise of Perennial Polyculture Farming?

The primary promise of perennial polyculture farming is most directly associated with reversing environmental degradation and redressing the loss of biodiversity. The promise of perennial polyculture farming in other areas—such as reducing worldwide hunger and malnutrition, reducing (particularly fossil fuel) energy use, and improving the health and education of women and children—is more indirect and will be addressed in a separate section.

**Figure 2**  
**Land Under Cultivation Worldwide**



SOURCE: Millennium Ecosystem Assessment, *Ecosystems and Human Well-Being: Synthesis*, Island Press, Washington, D.C., 2005, p. 3. Used with permission.

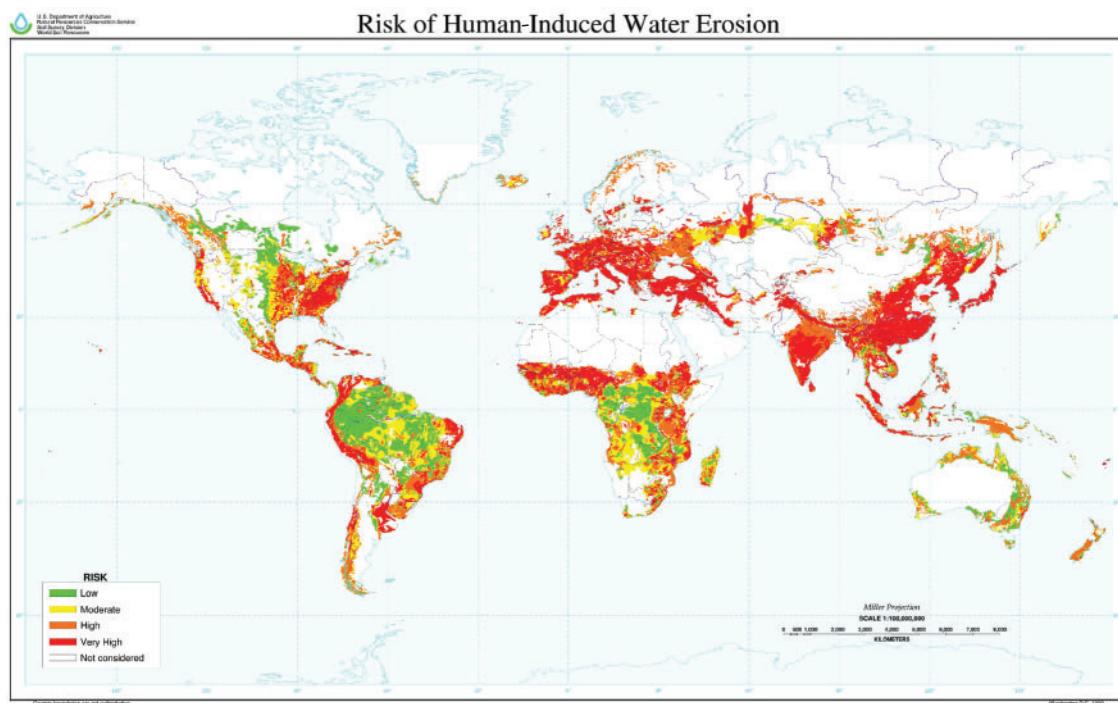
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### Effects on the Environment

The most direct desired effect of perennial polyculture farming is to address many of the environmental problems that are evident in today's annual monoculture approach. These include soil erosion and degradation, water depletion, and water contamination from fertilizers, herbicides, and pesticides. In thinking about replacing current annual, monoculture farming with perennial polyculture farming, it is important to understand what areas of the world are currently under cultivation. Figure 2 shows areas in which at least 30 percent of the landscape is under cultivation. The specific potential effects of perennial polycultures on the main types of environmental degradation throughout the world's cultivated lands follow.

**Erosion.** In the perfect archetype of the "reengineered prairie," a perennial polyculture would provide year-round ground cover, leading to a significant drop in soil erosion by both water and wind. Human-induced water and wind erosion are serious, worldwide problems for agriculture, primarily during the fallow periods of annual monoculture (and polyculture) farming. Figures 3 and 4 give some indication of the problem. Figure 3 shows those areas of the world that are vulnerable to water erosion. Figure 4 shows those areas of the world that are vulnerable to wind erosion. The most vulnerable regions in both maps are in red. A comparison of Figures 3 and 4 with Figure 2 suggests that a significant fraction of the world's land under cultivation is subject to water and wind erosion.

**Figure 3**  
**Water Erosion Vulnerability**



SOURCE: U.S. Department of Agriculture, Natural Resources Conservation Service, December 27, 2005. As of April 13, 2007: <http://soils.usda.gov/use/worldsoils/mapindex/>.

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For comparison, in the United States, soil erosion from water declined between 1982 and 2001, from 4.0 tons/acre to 2.7 tons/acre, and soil erosion from wind fell from 3.3 tons/acre to 2.1 tons/acre in the same period.<sup>5</sup> Total soil erosion of 4.8 tons per acre would result in the loss of an inch of topsoil from the average acre of cropland roughly every 25 years. This compares with typical soil formation rates of 300 to 1,000 years per inch.<sup>6</sup> Erosion in less developed countries is typically much greater than it is in the United States.

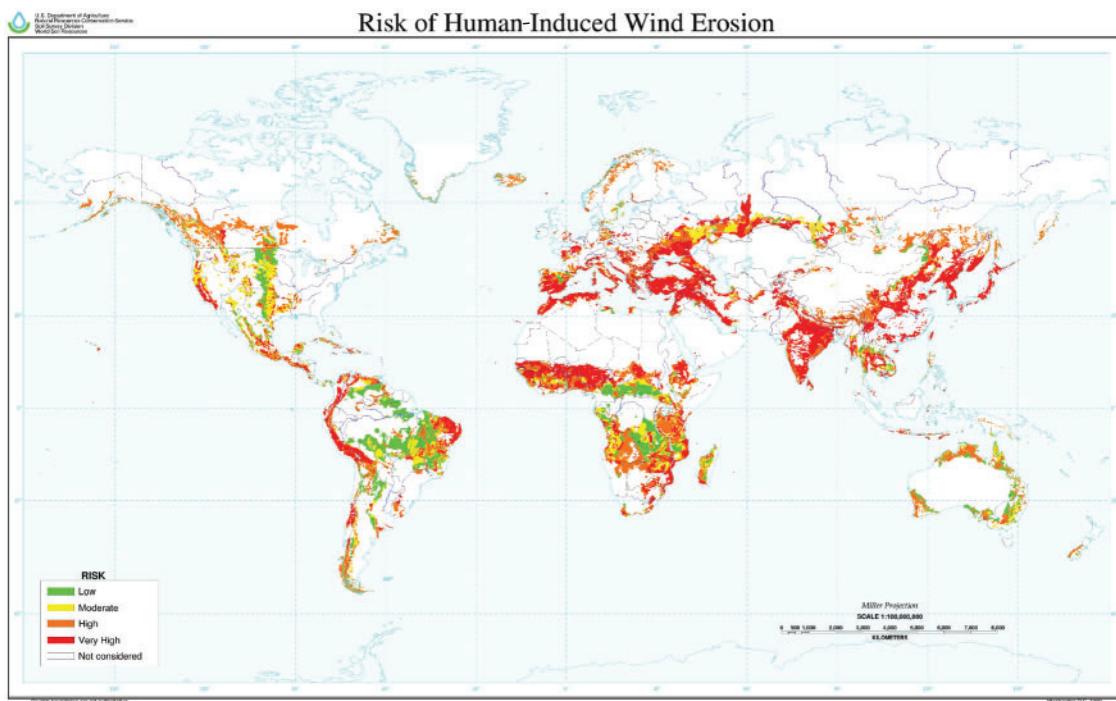
Besides providing year-round cover for croplands, perennials send their roots much deeper into the soil than do annuals, adding protection against soil erosion from water.

**Soil Degradation.** Land degradation more broadly refers to soil that has been eroded, that has lost its fertility through depletion of minerals and other nutrients, that has become salinized through a variety of mechanisms, or that has become contaminated by pesticides,

<sup>5</sup> Figures are based on U.S. Department of Agriculture, Natural Resources Conservation Service, *National Resources Inventory: 2001 Annual NRI*, July 2003. As of April 13, 2007: <http://www.nrcs.usda.gov/technical/land/nri01/nri01eros.html>.

<sup>6</sup> See Judith D. Soule and Jon K. Piper, *Farming in Nature's Image*, Island Press, Washington, D.C., 1992, p. 13.

**Figure 4**  
**Wind Erosion Vulnerability**



SOURCE: U.S. Department of Agriculture, Natural Resources Conservation Service, December 27, 2005.  
As of April 13, 2007: <http://soils.usda.gov/use/worldsoils/mapindex/>.

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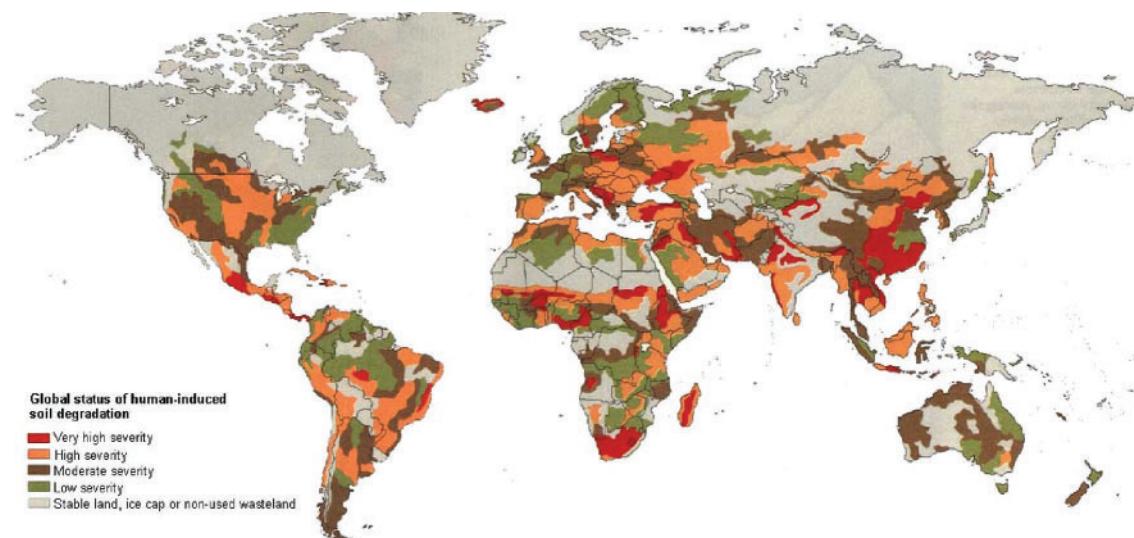
herbicides, or other means.<sup>7</sup> Figures 5 and 6 show two different views of worldwide land degradation. Figure 5 is from the Food and Agriculture Organization of the United Nations (FAO), and Figure 6 is from the International Soil Reference and Information Centre in the Netherlands. Exact measures of soil degradation and erosion are arguable, but the maps in Figures 3–6 indicate that agriculture that provides year-round cover, that requires much less pesticide and herbicide, and that provides much of its own nutrients would seriously reduce soil degradation worldwide.

**Water Depletion.** According to the American Association for the Advancement of Science (AAAS):

More than 60 percent of the water used in the world each year is diverted for irrigating crops . . . In Asia, which has two thirds of the world's irrigated land, 85 percent of water goes for irrigation. A worldwide doubling in the area under irrigation to more than 260 million hectares underpinned the "green revolution" that kept the world fed in the late 20th

<sup>7</sup> For more on land degradation, see, for example, Sara J. Scherr and Satya Yadav, "Land Degradation in the Developing World, Issues and Policy Options for 2020," 2020 Brief, No. 44, International Food Policy Research Institute, June 1997. As of April 13, 2007: <http://www.ifpri.org/2020/briefs/number44.htm>.

**Figure 5**  
Human-Induced Soil Degradation



SOURCE: Food and Agriculture Organization of the United Nations (FAO), *Dimensions of Need: An Atlas of Food and Agriculture*, FAO, Rome, Italy, 1995. Used with permission. As of April 13, 2007: [http://www.fao.org/documents/show\\_cdr.asp?url\\_file=docrep/u8480e/u8480e0d.htm](http://www.fao.org/documents/show_cdr.asp?url_file=docrep/u8480e/u8480e0d.htm).

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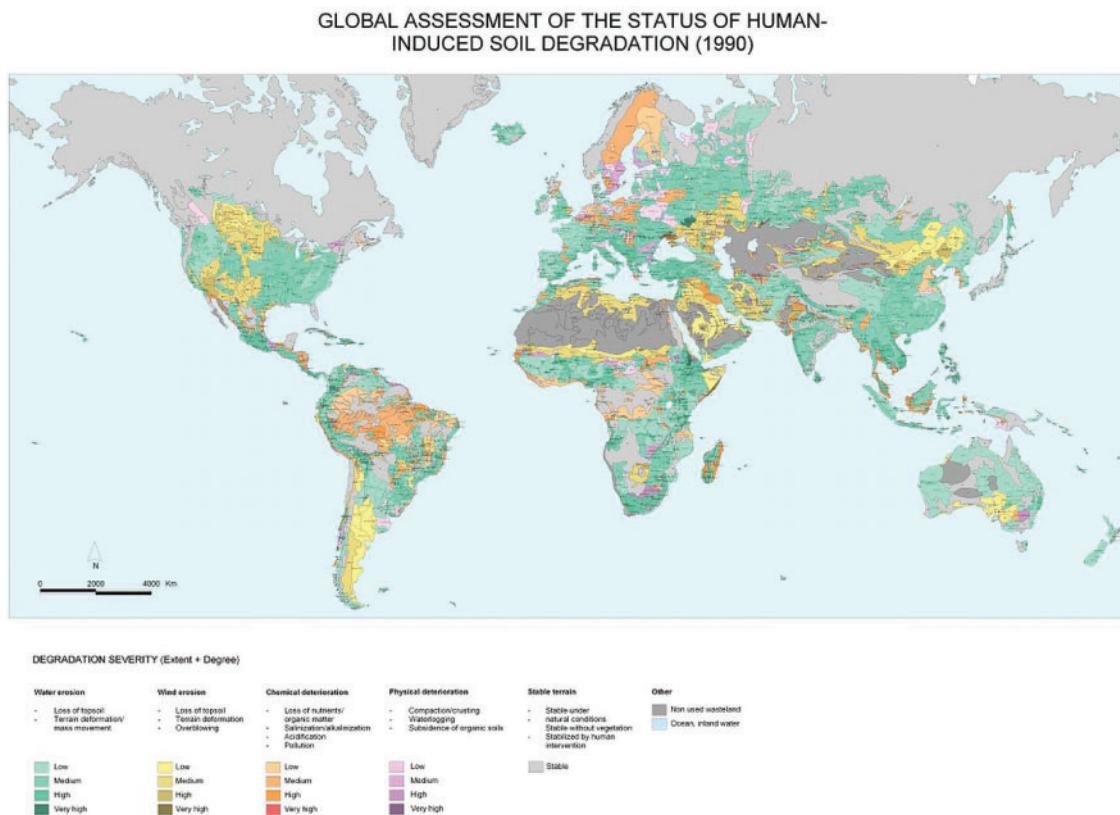
century. Almost 40 percent of the global food harvest now comes from the 17 percent of the world's croplands that are made productive in this way.<sup>8</sup>

Figure 7 shows the locations of the 17 percent of croplands that are made productive by irrigation (compare it with Figure 2). Again, according to the AAAS, “[m]ost irrigation schemes around the world are extremely inefficient. Typically, less than half the water reaches crop roots” (see footnote 8). This does not, however, mean that the other 83 percent of croplands use water efficiently. One measure of the efficient use of water for agriculture and other uses is the Water Poverty Index (WPI) developed at the Centre for Ecology and Hydrology in the UK. The WPI combines five factors: resources (the physical availability of surface and ground water), access (the extent of access to water for human uses), capacity (the effectiveness of the people's ability to manage water), use (the ways in which water is used—including agriculture), and environment (a measure of environmental integrity related to water).<sup>9</sup>

<sup>8</sup> Peter H. Gleick, *The World's Water: The Biennial Report on Freshwater Resources*, Island Press, Washington, D.C., 1998. Quoted in Paul Harrison, Fred Pearce, and Peter Raven, *AAAS Atlas of Population and Environment*, “Population and Natural Resources: Freshwater,” American Association for the Advancement of Science and University of California Press, Berkeley, Calif., 2000. As of April 13, 2007: <http://www.ourplanet.com/aaas/pages/natural03.html>.

<sup>9</sup> For more on this topic, see Natural Environment Research Council (NERC), Centre for Ecology & Hydrology, “The Water Poverty Index,” NERC, Swindon, UK, not dated. As of April 13, 2007: <http://www.ceh.ac.uk/sections/ph/WaterPovertyIndex.html>.

**Figure 6**  
**Soil Degradation**



SOURCE: International Soil Reference and Information Centre (ISRIC), Wageningen, Netherlands, 1990. Used with permission. As of April 13, 2007: <http://www.isric.org/UK/About+ISRIC/Projects/track+record/GLASOD.htm>.

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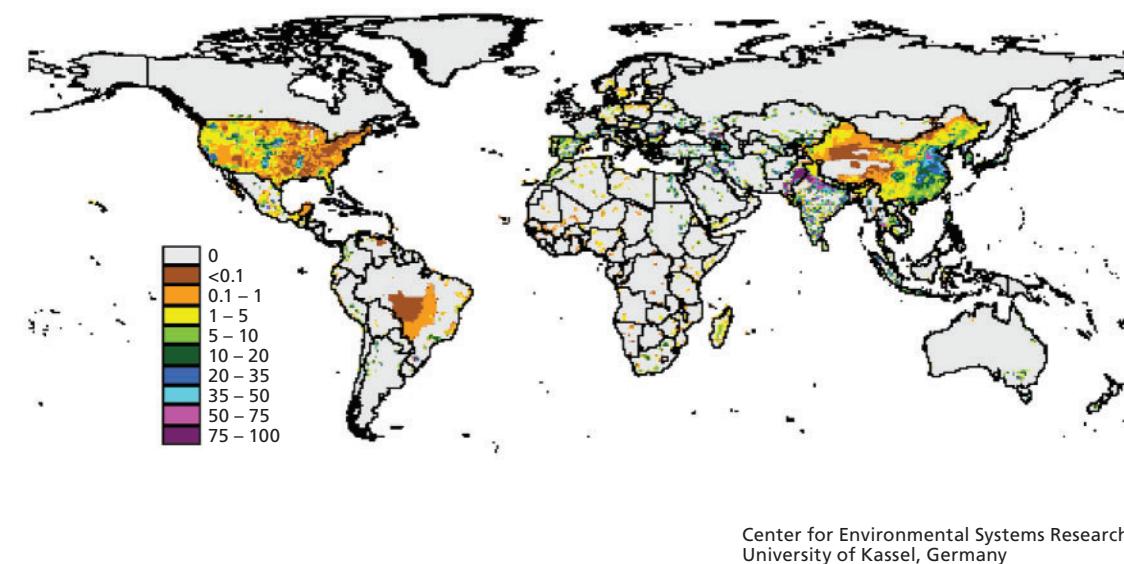
Combined with Figure 7, Figure 8 suggests that efficient use of water is a serious problem in most developing countries and in some developed countries as well.

Efficient use of water in agriculture, then, is important not only in countries that are wasting a lot of irrigation water, but also in countries that do not have a lot of water to waste. Perennial polycultures, with their constant ground cover (to take advantage of water whenever it falls) and deep roots (to capture more water than annual plants do) are more efficient at water usage than annual plants—and, in some cases, much more efficient.

**Water Contamination.** Freshwater systems are contaminated throughout the world. Agriculture is not the only source of freshwater contamination, but it is a major one. The FAO identifies agriculture “as the single largest user of freshwater on a global basis and as a major cause of degradation of surface and groundwater resources through erosion and chemical runoff.”<sup>10</sup> Common contaminants in freshwater systems from agricultural runoff include phosphorus,

<sup>10</sup> Edwin D. Ongley, “Control of Water Pollution from Agriculture,” FAO Irrigation and Drainage Paper 55, FAO, Rome, Italy, 1996. As of April 13, 2007: <http://www.fao.org/docrep/W2598E/w2598e04.htm#water%20quality%20as%20a%20global%20issue>.

**Figure 7**  
**Global Map of Irrigated Areas**



Center for Environmental Systems Research  
 University of Kassel, Germany  
 April 1999

SOURCE: Petra Döll and Stefan Siebert, *A Digital Global Map of Irrigated Areas: Documentation*, Kassel World Water Series, Report No. 1, University of Kassel, Center for Environmental Systems Research, Kassel, Germany, 2001. Used with permission. As of April 13, 2007:

[http://www.geo.unifrankfurt.de/igp/ag/dlf/publikationen/1999/doell\\_siebert\\_kwss1.pdf](http://www.geo.unifrankfurt.de/igp/ag/dlf/publikationen/1999/doell_siebert_kwss1.pdf).

NOTE: The map shows the fraction of each area that was equipped for irrigation in 1995.

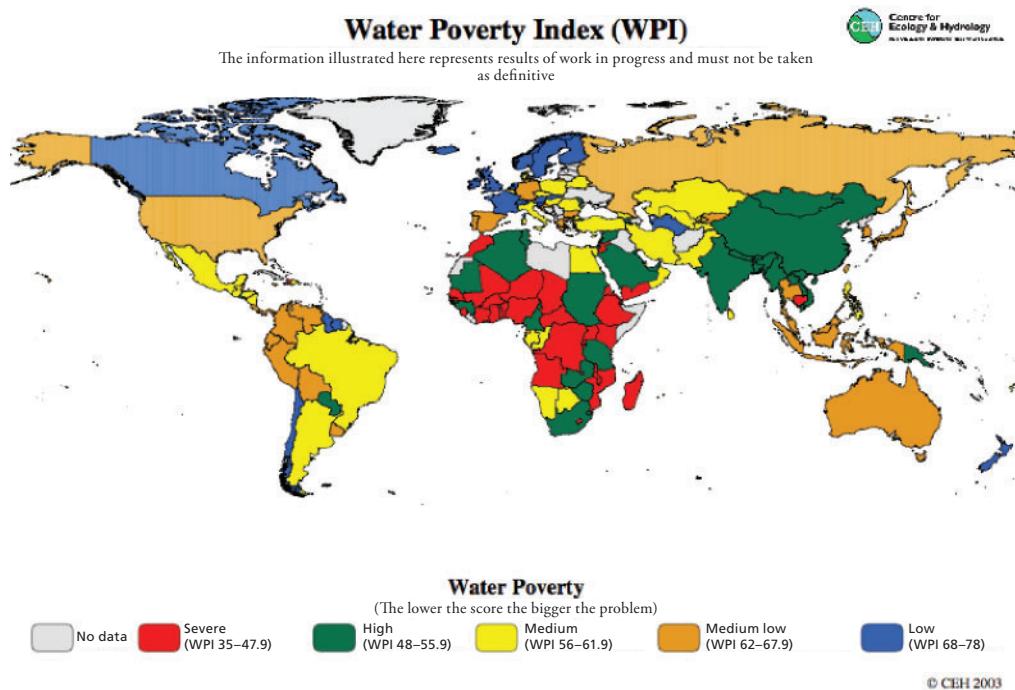
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nitrogen, metals, pathogens, sediment, pesticides, salt, and trace elements (e.g., selenium). The agricultural sources of those contaminants are primarily fertilizers, pesticides, and herbicides.

Maps of freshwater contamination would not tell the story of water contamination by agriculture because of the contributions from industry and other sources. There is one area, however, in which the agricultural contribution to water contamination is reasonably clear. That is in the dead zones in the world's oceans. A dead zone in the ocean is created by nitrogen and phosphorus (found in fertilizers) that wash down rivers and flow into the ocean. The nitrogen and phosphorus ignite algae and phytoplankton blooms. When these blooms die, they drop to the ocean floor and decompose, using up the oxygen of the deeper water. This severe depletion of oxygen—known as hypoxia—kills every oxygen-dependent sea creature in the area.

There are now some 146 dead zones in the oceans of the world, and they cover a total area measured in tens of thousands of square miles. The circles in Figure 9 are the major dead zones (as of 2002). The colors indicate whether the dead zones are annual (red), episodic (blue), periodic (pink), or persistent (yellow). Most are annual dead zones that appear in the summer and autumn and disappear over the winter. From the map, it is clear that most of the dead zones are related to intensive agriculture in developed countries, although there are now dead zones in such developing countries as China, Brazil, and Mexico. With continued emphasis

**Figure 8**  
**Water Poverty Index**



SOURCE: Natural Environment Research Council (NERC), Centre for Ecology & Hydrology, "The Water Poverty Index World Map," NERC, Swindon, UK, 2003. Used with permission. As of April 13, 2007: [http://www.ceh.ac.uk/sections/ph/documents/WPIworldmap\\_2.pdf](http://www.ceh.ac.uk/sections/ph/documents/WPIworldmap_2.pdf).

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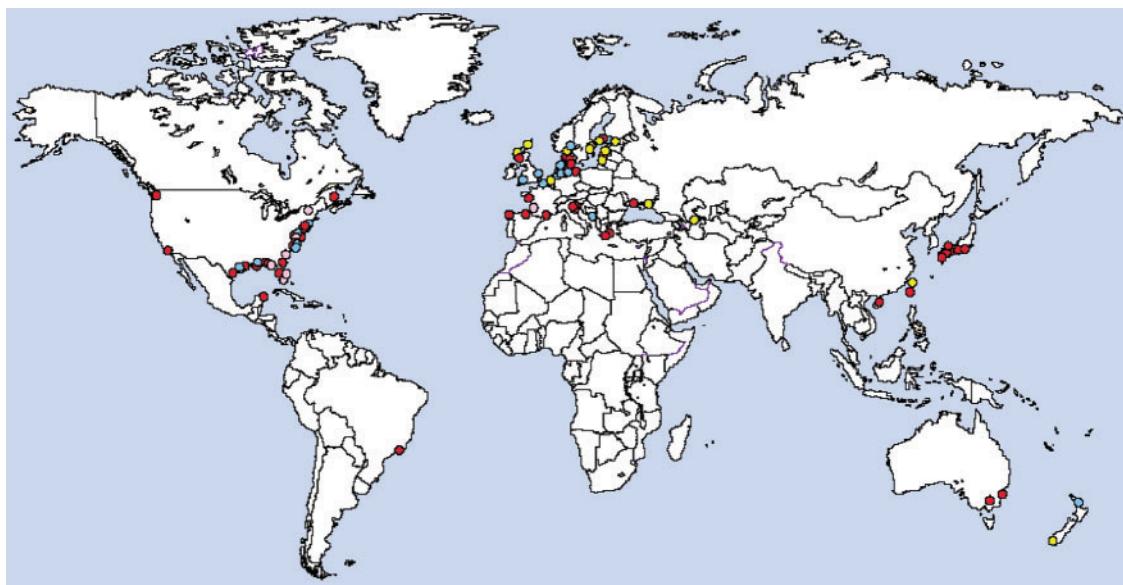
on fertilizers for improving productivity of agriculture in developing countries, dead zones are likely to continue to appear and to grow.

Agriculture's contribution to dead zones has been measured for some areas. Sources of nitrogen from the Mississippi River basin, for example, are estimated to include commercial fertilizers (41 percent); legumes (33 percent); animal manure (16 percent); atmospheric deposits (8 percent); and municipal and domestic wastes (1 percent).<sup>11</sup> Clearly, if perennial polycultures could significantly reduce (or eliminate) the amount of commercial and animal fertilizers required for food production, the contaminants in freshwater basins would be reduced and the oceans' dead zones would be significantly reduced.

We know that fertilizers, herbicides, pesticides, and other chemicals used in modern farming cause further contamination of ground water and waterways, but it is more difficult to

<sup>11</sup> Donald A. Goolsby and William A. Battaglin, "Nitrogen in the Mississippi Basin: Estimating Sources and Predicting Flux to the Gulf of Mexico," USGS Fact Sheet 135-00, December 2000, figure 5. As of April 13, 2007: <http://ks.water.usgs.gov/Kansas/pubs/fact-sheets/fs.135-00.html>. See also "Reducing Nutrient Loads, Especially Nitrate-Nitrogen, to Surface Water, Ground Water, and the Gulf of Mexico," Topic 5 Report for the Integrated Assessment on Hypoxia in the Gulf of Mexico, NOAA Coastal Ocean Program, Decision Analysis Series No. 19, May 1999.

**Figure 9**  
**Ocean Dead Zones**



SOURCE: United Nations Environment Programme (UNEP), Global Environment Outlook (GEO), *GEO Year Book 2003*, "Emerging Challenges—New Findings," UNEP, Nairobi, Kenya, 2002, p. 58. Used with permission. As of April 13, 2007: <http://www.mindfully.org/Water/2004/Oxygen-Starved-Zones1jan04.htm>.

NOTES: The 146 zones (shown as circles) are associated with either major population concentrations or water-sheds that deliver large quantities of nutrients to coastal waters. Annual (red): yearly events related to summer or autumnal stratification; episodic (blue): events occurring at irregular intervals greater than once per year; periodic (pink): events occurring at regular intervals shorter than once per year; and persistent (yellow): all-year-round hypoxia.

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say how much the situation would improve if those sources were significantly reduced because of the multisource nature of most water contamination. Nevertheless, in the best of scenarios, perennial polyculture farming could go a long way toward eliminating water and wind erosion, soil degradation, water depletion, and water contamination.

**Loss of Biodiversity.**<sup>12</sup> In its simplest form, biodiversity refers to the number and diversity of species, the genetic material of those species, and the natural communities, ecosystems, and landscapes of which those species are part. Biodiversity includes animal as well as plant species. It has been recognized as extremely important by the environmental and scientific communities because of its numerous benefits, and the current rate at which we are losing it is alarming. Increased human activities and a rapidly growing global population are threatening the Earth's biodiversity. Worldwide, numerous plant and animal species are becoming extinct every year, at an estimated loss of species in the tens of thousands per year.<sup>13</sup> Worldwide animal extinc-

<sup>12</sup> This subsection draws heavily on material provided by RAND colleague Beth Lachman, whose careful review has improved the paper in general.

<sup>13</sup> Robert Leo Smith and Thomas M. Smith, *Ecology and Field Biology*, Prentice Hall, Upper Saddle River, N.J., 6th ed., 2001, p. VII-A.

tion rates are estimated to be 1,000 to 10,000 times higher than natural extinction rates.<sup>14</sup> With these extinctions, natural systems that humans depend upon are degraded or lost, and the effects may be significant. Given current scientific knowledge, it is unclear at what point current biodiversity loss rates could lead to natural systems breaking down and critical problems; however, evidence of causes for concern already exists. For example, in California, habitat alterations and pesticide use have degraded natural ecosystems to the extent that few wild bees are left. California farmers, who have always relied on wild bees for pollination, must now rent bees to pollinate key agricultural crops.<sup>15</sup> Evidence of the global importance of biodiversity can be found in the signing of the Convention of Biodiversity by over 150 nations at the 1992 United Nations Earth Summit and the attention given to biodiversity conservation at the summer 2002 World Summit on Sustainable Development in Johannesburg, South Africa. A conservative estimate of the annual economic and environmental benefits of biodiversity in the United States is \$300 billion, and worldwide \$3 trillion.<sup>16</sup> Other estimates of the worldwide economic benefits of biodiversity range as high as \$33 trillion per year.<sup>17</sup>

In a natural prairie, there can be more than 200 plant species in a given area and perhaps several times that number of microscopic soil animals that are important to efficient prairie operation. A true reengineering of the prairie would dramatically increase the biodiversity over a monoculture on the same plot of land. However, any less-ambitious reengineering of the prairie that includes a variety of plant species in a perennial polyculture would contribute to the diversity of plant life over a monoculture and promote biodiversity more widely.

There are other ways in which perennial polyculture farming could help the environment (e.g., polycultures produce more plant material in the ground, thus sequestering more carbon dioxide), but the five areas outlined above represent the primary worldwide agriculture-induced environmental problems that could be mitigated.

## What Are Possible Secondary Benefits?

Beyond the more direct benefits of reversing environmental degradation and the loss of biodiversity, perennial polyculture farming holds the promise of indirectly addressing other global problems. These problems include global hunger and poverty, growing worries about fossil fuel

<sup>14</sup> R. S. Kellert and E. O. Wilson, eds., *The Biophilia Hypothesis*, Island Press, Washington, D.C., 1993.

<sup>15</sup> David Pimental et al., "Economic and Environmental Benefits of Biodiversity," *BioScience*, Vol. 47, No. 11, December 1997, pp. 747–757.

<sup>16</sup> These estimates are from Pimental et al., 1997. See this reference for a quantitative assessment of biodiversity benefits.

<sup>17</sup> For different approaches to arguing for and quantifying the importance and benefits of biodiversity, see R. Costanza et al., "The Value of the World's Ecosystem Services and Natural Capital," *Nature*, Vol. 387, May 15, 1997, pp. 253–260; Pimental et al., 1997; Gretchen C. Daily et al., "Valuing Ecosystem Services: Philosophical Framework and Empirical Approaches," in Donald Kennedy et al., *Nature's Services: Societal Dependence on Natural Ecocystems*, Island Press, Washington, D.C., 1997; B. A. Stein et al., *Precious Heritage: The Status of Biodiversity in the United States*, Oxford University Press, New York, 2000, pp. 93–118; and Smith and Smith, 2001.

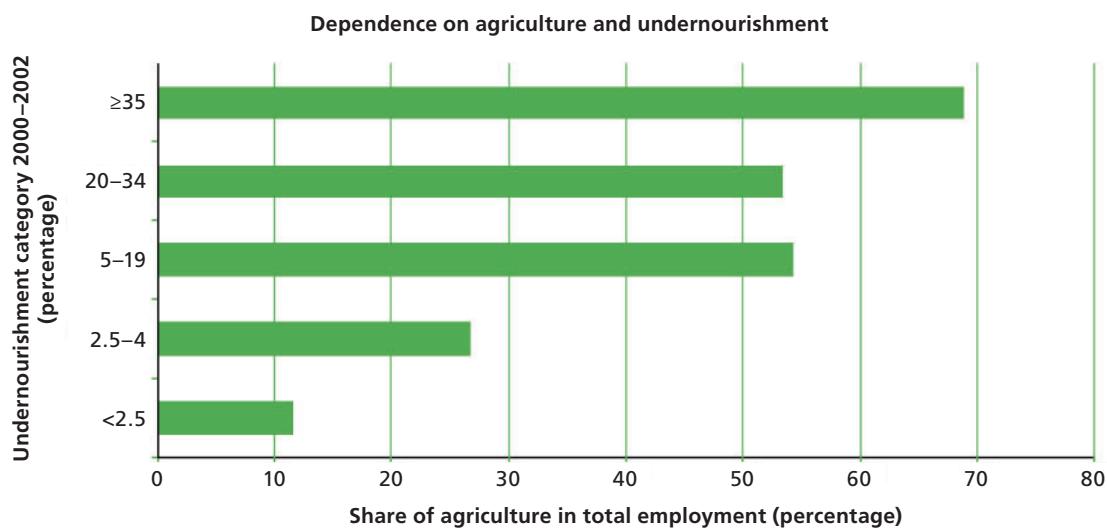
consumption, and the deteriorating state of health and education—especially among women and children—in developing countries.

### Reduction in Hunger and Poverty

The interconnections among hunger, poverty, and agriculture are manifold and complex. If one divides agriculture into commercial or industrial agriculture and subsistence agriculture, the latter—producing enough food to meet basic needs—is often equated with hunger and poverty. While the number of people in urban areas who live in poverty and are hungry has been on the rise for several decades, a wide majority of those who are poor and hungry are trying to get by on subsistence agriculture. Figure 10 is one measure of this prevalence, showing for example that in countries where more than 35 percent of the population is undernourished, almost 70 percent of the population is employed in agriculture.

If agricultural productivity could be improved, it would have beneficial effects on both hunger and poverty worldwide. There is, of course, a good deal of active research aimed at improving agricultural productivity—especially in developing countries. Much of the improvement available from Green Revolution technologies, however, comes from hybrid seeds (for annual monoculture farming) and from fertilizers, pesticides, and herbicides. But most subsistence agriculture in the world does not use these technologies. In fact, it often qualifies as organic simply because the farmer lacks the money to buy fertilizer, pesticides, or genetically modified seeds.

**Figure 10**  
**Agriculture and Undernourishment**



SOURCE: Food and Agriculture Organization of the United Nations, *Millennium Development Goal No. 1: Mobilizing Resources to Halve World Hunger*, FAO, Rome, Italy, 2005. Used with permission. As of April 13, 2007: [http://www.fao.org/documents/show\\_cdr.asp?url\\_file=/docrep/008/a0076e/a0076e00.htm](http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/008/a0076e/a0076e00.htm).

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Depending on the reasons for poor agricultural productivity, then, perennial polycultures could improve productivity and help reduce both hunger and poverty. The common causes for the failure of agricultural productivity to provide sufficient nourishment are poor soil; erosion; lack of money for seeds (especially the hybrid seeds of modern agriculture), fertilizers, pesticides, and herbicides; and poor irrigation/drought. Perennial polyculture agriculture could help in all of these areas.

Poor soil is common in developing countries with high levels of hunger and poverty (see Figures 5 and 6). Perennial polycultures could produce food crops while actually adding nitrogen to the soil. Soil erosion through water and wind erosion are also common problems in poor countries (see Figures 3 and 4). Perennial polycultures could produce food while stabilizing the soil year-round against both water and wind erosion. If the cost of hybrid seeds, fertilizers, pesticides, etc. is a problem, perennial polycultures could at least reduce the costs of seeds (because a year's worth of seeds will produce for several years rather than just one), fertilizers, herbicides, pesticides, and other farming equipment (see Reduced Energy Use below), making increased productivity less expensive. Finally, lack of water is another common factor in poor agricultural productivity. Figure 8 shows a general measure of water availability for all purposes, and Figure 11 shows how much freshwater is used in the agricultural sectors worldwide. Perennial polycultures could increase agricultural productivity through more efficient use of available water.

Typically, the individual problems related to agricultural productivity in subsistence agriculture are *all* present in cases of hunger and poverty. Therefore, the potential contribution of perennial polycultures to subsistence agriculture is all the more significant. Perennial polycultures bring the promise of producing more food at less cost for the poorest and hungriest in the world. According to one report:

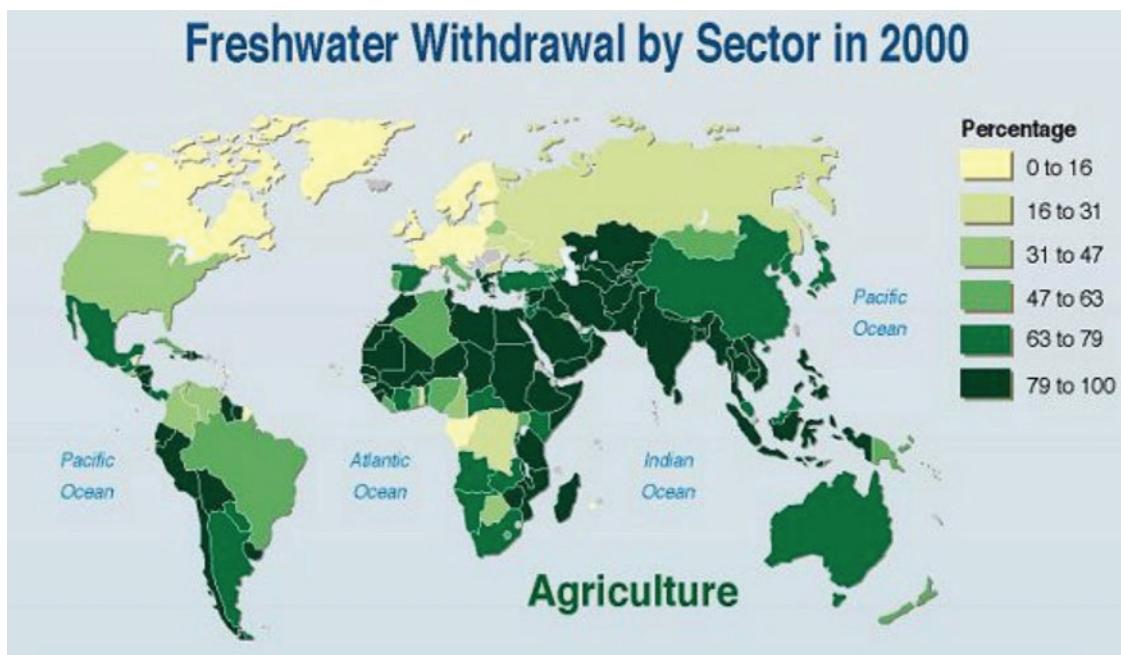
Evidence consistently shows that agricultural growth is highly effective in reducing poverty. It has been reported that every 1% increase in per capita agricultural output led to a 1.6% increase in the incomes of the poorest 20% of the population. Another study concluded from a major cross-country analysis that, on average, every 1% increase in agricultural yields reduced the number of people living on less than a dollar a day by 0.83%.<sup>18</sup>

There is one additional advantage of perennial polycultures over annual monocultures in areas of hunger and poverty—perennial polycultures are “scale neutral.” That is, annual monocultures work most efficiently on a large scale, but perennial polycultures work well at any scale, from small family farm to large open prairie. This factor makes them particularly adaptable to parts of the world that could most benefit from their other strengths.

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<sup>18</sup> Calestous Juma, ed., *Going for Growth: Science, Technology and Innovation in Africa*, The Smith Institute, London, 2005, p. 75. As of April 13, 2007: [http://bcisia.ksg.harvard.edu/BCSIA\\_content/documents/GoingforGrowth\\_AMENDEDFINAL.pdf](http://bcisia.ksg.harvard.edu/BCSIA_content/documents/GoingforGrowth_AMENDEDFINAL.pdf). The studies mentioned are J. Gallup, S. Radelet, and A. Warner, “Economic Growth and the Income of the Poor,” CAER II discussion paper, No. 36, Harvard Institute for International Development, 1997; C. Thirtle, X. Irz, L. Lin, V. McKenzie-Hill, and S. Wiggins, *Relationship Between Changes in Agricultural Productivity & the Incidence of Poverty in Developing Countries*, report commissioned by the Department for International Development, London, 2001.

**Figure 11**  
Worldwide Freshwater Agriculture Usage



SOURCE: United Nations Environment Programme, *Vital Water Graphics: An Overview of the State of the World's Fresh and Marine Waters*, UNEP, Nairobi, Kenya, 2002. Used with permission. As of April 13, 2007: <http://www.unep.org/vitalwater/15.htm>.

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### Reduced Energy Use

The impact of perennial polycultures on energy use would primarily be in developed countries where food production now accounts for 17 percent of all energy use (though only 2 to 5 percent is actually consumed on the farm), but it is worth at least a brief mention here. Since the early 20th century, the amount of energy required per hectare of corn production, for example, has increased over tenfold.<sup>19</sup> Of the energy used in the food production system, the large amounts of energy that are used in operating heavy farming machinery and in producing and transporting seeds, fertilizers, pesticides, and herbicides could be substantially saved by using perennial polycultures. Fertilizers containing nitrogen are particularly fossil-fuel intensive. According to The Fertilizer Institute, in the year from June 30, 2001, until June 30, 2002, the United States used 12,009,300 short tons of nitrogen fertilizer.<sup>20</sup> Using a nominal figure

<sup>19</sup> Soule and Piper, 1992, p. 22.

<sup>20</sup> These data were originally available as "U.S. Fertilizer Use" from The Fertilizer Institute, Washington, D.C., at <http://www.tfi.org/Statistics/USfertuse2.asp>, but they have since been omitted from that Web site. Other references include Dale Allen Pfeiffer, *Eating Fossil Fuels*, from the Wilderness Publications, Ashland, Oreg., 2003 (as of April 13, 2007: <http://www.oilcrash.com/articles/eating.htm>); and Bruce Sundquist, *The Earth's Carrying*

of 1.4 liters of diesel equivalent per kilogram of nitrogen, this equates to the energy content of 96.2 million barrels of diesel fuel.

### Improved Health and Education

Industrial agriculture, with its pesticides, herbicides, fungicides, etc., contributes to a growing worldwide health problem among agricultural workers and others. Even though industrial agriculture is disproportionately pursued in developed countries, the World Health Organization estimates that there are as many as one million serious unintentional pesticide poisonings each year worldwide, and many of these are in developing countries.<sup>21</sup> Clearly, a reduction in pesticides, herbicides, etc. because of switching to perennial polycultures could reduce this health burden.

Other health hazards to agricultural workers, such as machinery accidents, could also be detailed, but there is a more interesting angle to the potential impact of perennial polycultures on health and education—the health and education of women and children. If perennial polycultures help reduce undernourishment, there is clearly a positive effect on the health, and secondarily on the education, of children. And there is another potential health and education benefit of perennial polycultures, because women are significantly involved in subsistence agriculture in developing countries. Figure 12 shows the number of female agricultural workers per 100 male agricultural workers by country. Numbers at 100 or more indicate that more than 50 percent of the agricultural workers of a country are women. Furthermore, Figure 13 shows that the percentage of women in the agricultural workforce has gone up significantly in the last 50 years (while the overall agricultural workforce has shrunk).

If perennial polycultures could reduce the amount of tilling, planting, weeding, fertilizing, and pest killing required in agriculture, they could reduce the work burden of women in subsistence agriculture situations. What women in areas of subsistence agriculture might do with more time is, of course, a matter of speculation. What *can* be said, however, is that one of the causes of a lack of education among women and girls in areas of subsistence agriculture is their increased responsibilities over time in agricultural activities.<sup>22</sup> Further, research shows that educated women marry later, space their pregnancies better, seek medical attention for their children in case of illness, provide better child care, and provide better nutrition for their children—all of which helps to ensure that their children are better educated.<sup>23</sup>

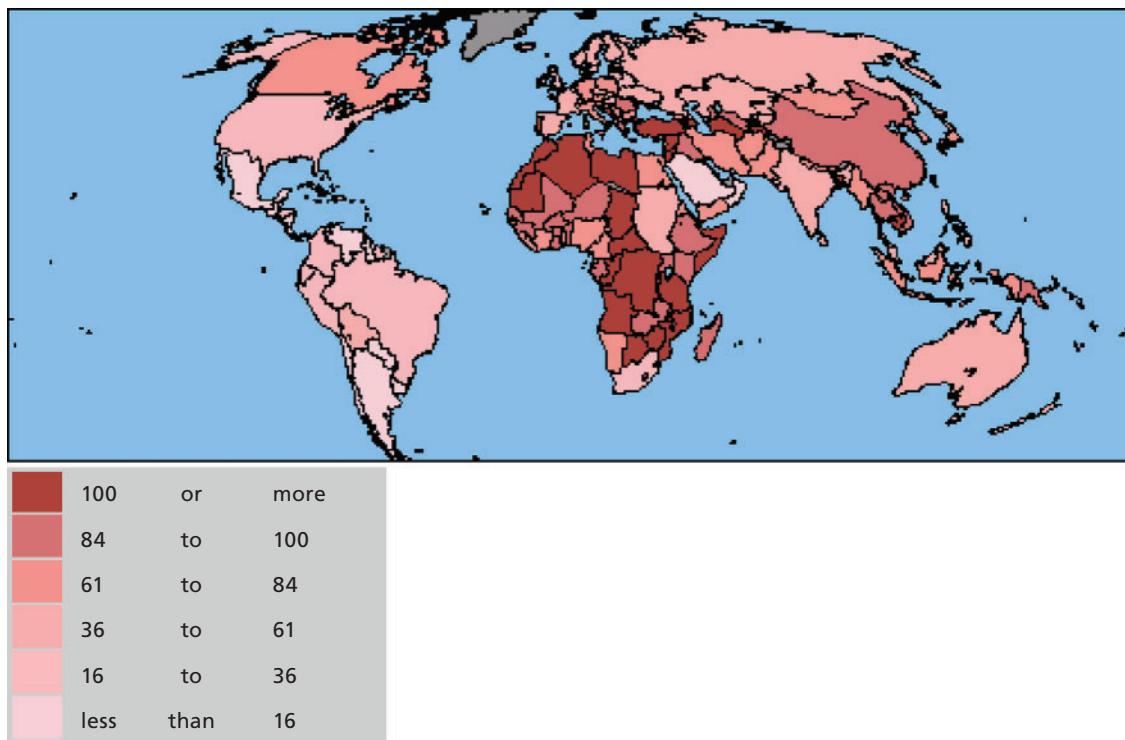
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<sup>21</sup> J. Jeyaratnam, "Acute Pesticide Poisoning: A Major Global Health Problem," *World Health Statistics Quarterly*, Vol. 43, No. 3, 1990, pp. 139–144.

<sup>22</sup> See, for example, Merilee Karl, "Higher Agricultural Education and Opportunities in Rural Development for Women—An Overview and Summary of Five Case-Studies," Food and Agriculture Organization of the United Nations, Rome, Italy, 1997. As of April 13, 2007: <http://www.fao.org/docrep/W6038E/w6038e00.htm>.

<sup>23</sup> See Kalanidhi Subbarao and Laura Raney, *Social Gains from Female Education: A Cross-National Study*, World Bank Discussion Paper 194, World Bank, Washington, D.C., 1993; and Lawrence H. Summers, *Investing in All the People: Educating Women in Developing Countries*, EDI Seminar Paper 45, World Bank, Washington, D.C., 1994.

**Figure 12**  
**Ratio of Female to Male Agricultural Population (in percentage), 2000**



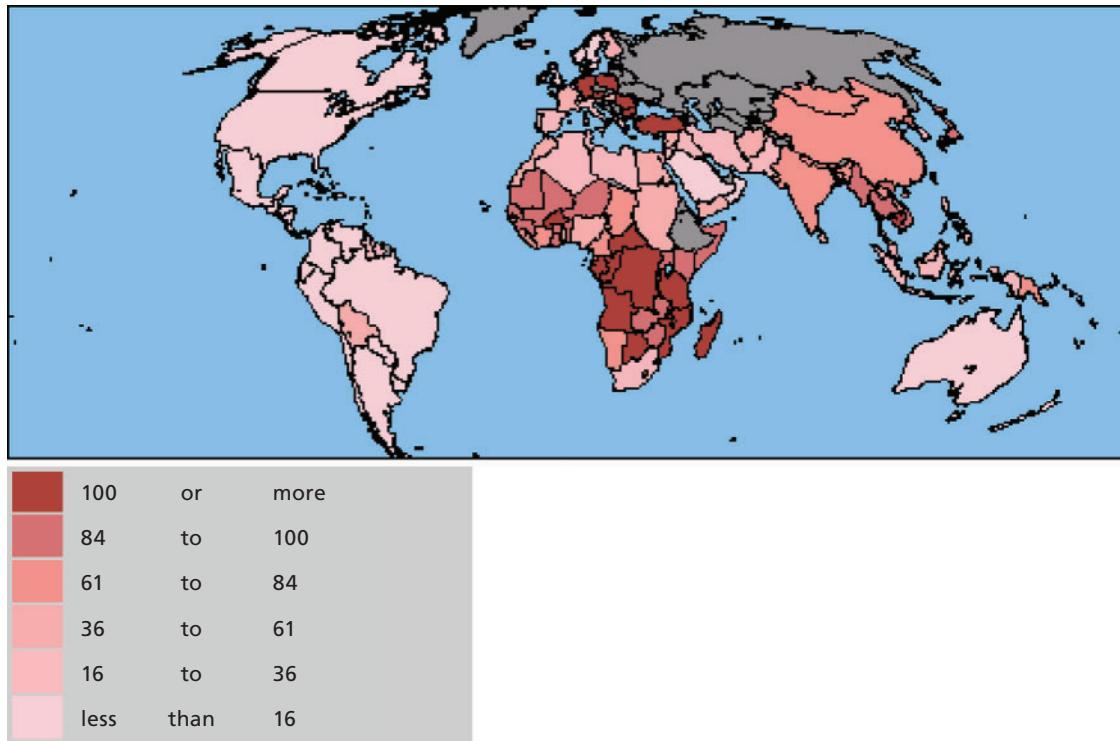
SOURCE: Food and Agriculture Organization of the United Nations, *Gender and Food Security: Statistics, "Gender Statistics and Maps,"* FAO, Rome, Italy, not dated. Used with permission. As of April 13, 2007: <http://www.fao.org/Gender/en/stats-e.htm>.

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There is some evidence, however, that reductions in tilling, planting, weeding, etc. may be offset by the requirement for more management of polycultures. For example, one collection of papers concluded that polycultures need “higher management” and “an evolving, adaptive management regime.”<sup>24</sup> Yet, other studies suggest that polycultures will reduce seasonal work peaks (in which women and children are most likely to be involved). Much of this is speculative, however, because there is virtually no labor data on current-day polyculture farming. Determining the actual ability of perennial polycultures to reduce the role of women (and children) in subsistence agriculture (and what women and children might do with their increased time), then, must await further data.

<sup>24</sup> E. C. Lefroy, R. J. Hobbs, M. H. O’Connor, and J. S. Pate, “What Can Agriculture Learn from Natural Ecosystems?” *Agroforestry Systems*, Vol. 45, Numbers 1–3, March 1999, pp. 425–438 (referenced in Larry Geno and Barbara Geno, *Polyculture Production: Principles, Benefits and Risks of Multiple Cropping Land Management Systems for Australia*, Rural Industries Research and Development Corporation, Barton, Australian Capital Territory, Publication No. 01/34, May 2001). It is interesting to note that the same set of studies in Lefroy et al. concluded that “perennial plants in polyculture will likely be the base of successful mimics” of natural ecosystems.

**Figure 13**  
**Ratio of Female to Male Agricultural Population (in percentage), 1950**



SOURCE: Food and Agriculture Organization of the United Nations, *Gender and Food Security: Statistics, "Gender Statistics and Maps,"* FAO, Rome, Italy, not dated. Used with permission. As of April 13, 2007: <http://www.fao.org/Gender/en/stats-e.htm>.

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## Is Perennial Polyculture Farming Truly Feasible?

Up to this point, the speculation has relied on the promise of perennial polyculture agriculture. *If* that promise could be realized, it could have revolutionary effects on the world's poor, hungry, and uneducated, and on the sustainability of the world's agriculture. It is now time to start asking some tough questions about that promise.

### Isn't the Concept Too Simplistic?

Isn't it a bit far-fetched to think that something so simple could have such a significant effect? Perhaps. On the other hand, just because it is simple is not a good reason to dismiss it out of hand. To see this, one has only to look at the most recent agricultural revolution—the so-called Green Revolution. That revolution began in 1943 when the Rockefeller Foundation and the Mexican government established the Cooperative Wheat Research and Production Program to improve the agricultural output of the country's farms. The program was a resounding success. Mexico went from importing half its wheat in 1943 to self-sufficiency by 1956 and, by 1964, to exporting half a million tons of wheat. That success was quickly continued in India

and Pakistan where, on average, the program tripled wheat and other food crop harvests per hectare and saved perhaps a billion people from hunger and starvation.<sup>25</sup>

The program's success was due primarily to the development of high-yielding hybrid strains (produced mainly through cross-breeding) and to new agricultural techniques. The major new techniques were extensive use of chemical fertilizers, improved irrigation methods, more widespread use of heavy machinery, and the development of chemical pesticides and herbicides. A single (ongoing) program, begun in Mexico and using generally available technology, produced a tripling of crop yields over methods that had been in use for centuries.

There is reason to speculate then, that a new program, relying on perennial polycultures and using new technologies to improve crop yields, could produce a breakthrough in high-yield crops with reduced needs for machinery and chemical interventions.

### Why Hasn't Anybody Tried This Before?

If perennial polycultures are such a good idea, why haven't they been developed before now? Certainly the polyculture part has been explored and developed to some extent. One source suggests that "humans have produced food from integrated polycultures for approximately 98.5% of farming history."<sup>26</sup> Modern farmers use a wide variety of techniques today that emulate aspects of a perennial polyculture. They use crop rotations to reduce the need for pest control and fertilizer; use cover crops to improve soil quality, prevent soil erosion, and minimize weed growth; use no-till and low-till farming to minimize soil erosion and increase retention of water and nutrients; practice soil management to improve fertility; employ diversity to protect against monoculture vulnerabilities; use integrated pest management to reduce the need for pesticides; and employ rotational grazing to prevent soil erosion and contribute to soil fertility.<sup>27</sup>

Using perennials, however, has been virtually absent from modern experiments in agriculture primarily because the goal in agriculture has generally been to achieve high yield and *everyone knows* that annuals put their energy into producing seeds while perennials put their energy into producing roots and rhizomes. There have been some past attempts to investigate perennial grains, particularly wheat. As long ago as the 1920s, the Russians had a large perennial wheat breeding program, and there have been sporadic efforts since then. It was not until the mid-1970s, however, that Wes Jackson argued for perennial polycultures, founded The Land Institute, and introduced the notion that perennial polycultures could be developed into

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<sup>25</sup> This program won its developer, Dr. Norman Borlaug, the Nobel Prize in 1970, and the story about the program has been recounted in many places. See, for example, The Nobel Foundation Web site biography of Norman Borlaug, 1970. As of April 13, 2007: [http://nobelprize.org/nobel\\_prizes/peace/laureates/1970/borlaug-bio.html](http://nobelprize.org/nobel_prizes/peace/laureates/1970/borlaug-bio.html).

<sup>26</sup> Geno and Geno, 2001, p. 10.

<sup>27</sup> Leo Horrigan, Robert S. Lawrence, and Polly Walker, "How Sustainable Agriculture Can Address the Environmental and Human Health Harms of Industrial Agriculture," *Research Review*, Center for a Livable Future, Johns Hopkins Bloomberg School of Public Health, Vol. 110, No. 5, May 2002, pp. 445–456. As of April 13, 2007: [http://www.jhsph.edu/clf/PDF%20Files/Sustainable\\_Ag\\_Horrigan.pdf](http://www.jhsph.edu/clf/PDF%20Files/Sustainable_Ag_Horrigan.pdf).

“an agricultural system with the ecological stability of the prairie and a grain yield comparable to that from annual crops.”<sup>28</sup>

More recently, people have begun to pay more attention to the potential of perennials in agriculture. In a study on the economic benefits of the Earth’s biota, David Pimentel and colleagues concluded that:

Cultivating perennial cereal grains that can be harvested continuously for 4 to 5 years without tilling and replanting—in place of annual grains whose energy-intensive spring and fall tilling exposes soil to wind and water erosion—could reduce erosion as much as 50 percent, saving \$20 billion worth of soil and \$9 billion in tractor fuel every year in the United States. . . . Genes for perennial cereal grains already exist in wild plant species.<sup>29</sup>

### What Is the Evidence That Perennial Polyculture Farming Could Work?

There is research being conducted on perennial polycultures at The Land Institute and The Rodale Institute.<sup>30</sup> The Land Institute, for example, is experimenting with polycultures involving warm-season grasses (such as eastern gamagrass), cool-season grasses (such as mammoth wild rye), legumes (such as Illinois bundleflower and wild senna), and composites (such as Maximilian sunflower) all growing together in mixed intercropping.

To answer this question more specifically, it is useful to replace it with four questions that The Land Institute asks itself:

- Can perennialism and increased seed yield go together?
- Can a polyculture of species overyield a monoculture?
- Can perennial polyculture sponsor all its nitrogen needs?
- Can perennial species adequately manage pests?

Laura Jackson at the University of Northern Iowa identified a mutant strain of eastern gamagrass whose seed production is four times greater than normal—without any corresponding loss of root mass or vigor.<sup>31</sup> That alone should be sufficient evidence of a yes answer to the first question. There is ample evidence beyond that, however, that seed yields of perennials can be improved without significant loss of root mass. And most of this research has not involved direct genetic engineering of perennial plants—a potential route to further increases in yield.

Yields of a single perennial species can approach those of annual monocultures (70 percent or more). However, more important, can a perennial polyculture “overyield” an annual monoculture in the sense of producing more food per plot of land than does the annual mono-

<sup>28</sup> See The Land Institute general Web site and, specifically, “About Us: Introduction and Mission.” As of April 13, 2007: <http://www.landinstitute.org>.

<sup>29</sup> D. Pimentel, C. Wilson, C. McCullum, R. Huang, P. Dwen, J. Flack, Q. Tran, T. Saltman, and B. Cliff, “Economic and Environmental Benefits of Biodiversity,” *BioScience*, Vol. 47, No. 11, December 1997, p. 755.

<sup>30</sup> More information is available at the institutes’ Web sites. As of April 13, 2007: <http://www.landinstitute.org> and <http://www.rodaleinstitute.org>.

<sup>31</sup> See Scott Russell Sanders, “Learning from the Prairie,” *The Witness*, Vol. 84, No. 5, May 2001.

culture? Overyield in polycultures is common. One study concluded that the yield advantage of intercropping (interspersing rows of different crops) was small (5 to 15 percent) but consistent.<sup>32</sup> The traditional corn/beans/squash polyculture of Mexico produces overyields as high as 50 percent,<sup>33</sup> and other studies have found overyields as high as 150 percent.<sup>34</sup>

The remaining question, then, is whether an overyield is possible with a *perennial* polyculture. There is increasing evidence that it is. For example, The Land Institute has obtained a 19 percent overyield with a mixture of eastern gamagrass and Illinois bundleflower, and in a three-species mixture of eastern gamagrass, Illinois bundleflower, and the cool season (C3) mammoth wild rye, the institute observed a 26 percent overyield.<sup>35</sup>

There is *prima facie* evidence from ancient prairies that perennial polycultures can sponsor all their nitrogen needs. The more important question is whether a specific set of perennials can produce enough nitrogen to both yield a crop and maintain its nitrogen level. Here the evidence is more indirect, but there is experimental evidence, for example, that a plant like Illinois bundleflower can improve available soil nitrogen status over several years, despite having its seeds removed annually (see footnote 35).

There is ample evidence that plant mixtures aid pest control. As one source puts it:

There are two schools of thought on why this occurs. One suggests that higher natural enemy populations persist in diverse mixtures due to more continuous food sources (nectar, pollen, and prey) and favorable habitat. The other thought is that pest insects that feed on only one type of plant have greater opportunity to feed, move around in, and breed in pure crop stands because their resources are more concentrated than they would be in a crop mixture. Regardless of which reason you accept, the crops growing together in the mixture complement one another, resulting in lower pest levels. Intercropping also aids pest control efforts by reducing the ability of the pest insects to recognize their host plants. For example, thrips and white flies are attracted to green plants with a brown (soil) background, ignoring areas where vegetation cover is complete.<sup>36</sup>

<sup>32</sup> R. W. Snaydon and P. M. Harris, "Interactions Below Ground—The Use of Nutrients and Water," in *Proceedings of the International Workshop on Intercropping*, R. Willey, ed., International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andhra Pradesh, India, 1981, pp. 188–201 (referenced in Geno and Geno, 2001).

<sup>33</sup> S. R. Gliessman, "Sustainable Agriculture: An Agroecological Perspective," in John Andrews and Inez Tommerup, eds., *Advances in Plant Pathology*, Vol. 11, Academic Press, London, 1995, pp. 45–57 (referenced in Geno and Geno, 2001).

<sup>34</sup> M. Liebman, "Polyculture Cropping Systems," in *Agroecology: The Science of Sustainable Agriculture*, M. A. Altieri, ed., Intermediate Technology Publications, London, 1995, pp. 205–218 (referenced in Geno and Geno, 2001).

<sup>35</sup> Jon Piper, "Natural Systems Agricultural Research," in M. Hackett and S. H. Sohmer, eds., *Proceedings of the Ecology of Our Landscape: The Botany of Where We Live, Exploring the Interfaces Between Plants, People, and the Environment*, The Botanical Research Institute of Texas and Texas Christian University, Fort Worth, Tex., 1996. As of April 13, 2007: <http://www.landinstitute.org/vnews/display.v/ART/2001/03/10/37825ab33>.

<sup>36</sup> Preston Sullivan, *Intercropping Principles and Production Practices*, ATTRA Publication #IP135, National Sustainable Agriculture Information Service, Fayetteville, Ark., 2003. As of April 13, 2007: <http://www.attra.org/attra-pub/intercrop.html>.

This is not exactly the same as saying that perennial polycultures can *adequately* manage their pests, but the principles are the same, and there is every reason to expect that perennial polycultures will require less pesticide than do annual monocultures.<sup>37</sup>

These are not the only questions that can be asked about the feasibility of perennial polycultures, but they are the main questions. Even partial “yes” answers to all four are strong evidence that the potential of perennial polycultures is worth pursuing.

Given that perennial polycultures might be a feasible alternative to monocultures from an agricultural standpoint, the two most important follow-on questions would be about the food value of perennial polyculture species and their overall economic viability. With respect to food value, again there is preliminary evidence that species being tested in perennial polycultures could compete with monoculture foods. A study of eastern gamagrass, for example, concluded:

As a food source, the nutritional value of gamagrass grain is impressive. The protein content of the grain is 27% while that of wheat and corn is about 17 and 10%, respectively. Gamagrass grain also has twice as much of the amino acid methionine as corn and is about 51% carbohydrate. Gamagrass is readily digestible and, in addition, tastes good. It has a distinctive corn-nutty flavor when popped or ground into flour.<sup>38</sup>

In addition, one of the most promising nitrogen-fixing legumes, Illinois bundleflower, while a favorite food of grazing animals, is also a possibility for human consumption:

The seed of Illinois bundleflower is high in protein: 38% on a dry weight basis. For comparison, soybeans are 40% protein. To test for protein digestibility, we sent cooked and uncooked seed to the University of Nebraska’s Food Protein Research Group. Protein from uncooked seed was 69% digestible; protein from seed boiled for 60 minutes was 83% digestible. An estimate of the degree to which protein is utilized in the human body is called the computed Protein Efficiency Ratio (c-PER); Illinois bundleflower’s c-PER is close to that of cooked oats, at 1.8.<sup>39</sup>

The economic viability of perennial polycultures is more difficult to gauge at this point. Since the concept of perennial polycultures is still in its exploratory phase, overall economic comparability with annual monocultures is hard to judge. If the savings in energy and labor with perennial polycultures can be realized and issues related to harvesting can be solved expe-

<sup>37</sup> The general ability of mixed plants to manage pests better than monocultures is widely acknowledged in the agricultural world. See, for example, Nadia El-Hage Scialabba and Douglas Williamson, *The Scope of Organic Agriculture, Sustainable Forest Management and Ecoforestry in Protected Area Management*, Environment and Natural Resources Working Paper No. 18, Food and Agriculture Organization of the United Nations, Rome, Italy, 2004. As of April 13, 2007: <http://www.fao.org/docrep/007/y5558e/y5558e00.htm>.

<sup>38</sup> Patricia R. Boehner, “Eastern Gamagrass: In Transition from Forage to Food Crop,” *The Land Report*, Vol. 31, 1987, pp. 8–12.

<sup>39</sup> J. Vail, P. Kulakow, and L. Benson, “Illinois Bundleflower: Prospects for a Perennial Seed Crop, in D. D. Smith and C. A. Jacobs, eds., *Proceedings of the Twelfth North American Prairie Conference: Recapturing a Vanishing Heritage*, University of Northern Iowa, Cedar Falls, 1992, pp. 31–32.

ditiously, there is reason to believe that perennial polycultures could be more cost-effective than annual monocultures. Conversely, if management of perennial polycultures is more complicated than with annual monocultures, for example, the hoped-for savings could disappear. The one current attempt related to the costs of perennial polycultures is the Sunshine Farm Research Program of The Land Institute. According to the institute:

The Land Institute is using the prairie as a model for the Sunshine Farm. The main goal of the project is to conduct year-round accounting of energy, materials, and labor on the farm. The aims are to examine whether the Sunshine Farm can provide its fuel and fertility, and to determine how much industrial energy society must provide from sunlight to manufacture the farm facilities, equipment, and inputs. Prairies are characterized by species diversity, perennial plants, energy flows based on sunlight, and internal control of fertility and pest damage. Hence, the Sunshine Farm contains renewable energy technologies and innovative farming practices applied to conventional crops and animals. Import of nutrients is minimal, and some candidates are included from The Land Institute's natural systems agriculture research.<sup>40</sup>

### Should Perennial Polycultures Replace Annual Monocultures?

Not even its advocates envision perennial polycultures replacing all annual monoculture crops. Advocates do, however, argue that it makes sense to replace annual monocultures with perennial polycultures on marginal land and on highly erodible soils. In the latter case, that could be quite extensive. In the United States alone, 350 million of the 400 million tillable acres (87.5 percent) are mildly to highly erodible and would, thus, be candidates for perennial polycultures.<sup>41</sup>

### Where Should We Go from Here?

To literally reengineer an ancient prairie to produce food for humans at a level anywhere near the yields of annual monocultures would be a complex problem indeed. As mentioned earlier, in a natural prairie, there can be more than 200 plant species in a given area and perhaps several times that number of important microscopic soil animals. To reengineer that plant-animal complex for specific yield characteristics would be a combinatorial problem of enormous magnitude. Even the problem of optimizing a perennial polyculture of just a few species is a very complex undertaking. Just evaluating the yield of a single perennial grain, such as intermediate wheatgrass, involves several considerations:

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<sup>40</sup> Marty Bender, "The 150-Acre Sunshine Farm at The Land Institute," in M. Hackett and S. H. Sohmer, eds., *Proceedings of the Ecology of Our Landscape: The Botany of Where We Live, Exploring the Interfaces Between Plants, People, and the Environment*, The Botanical Research Institute of Texas and Texas Christian University, Fort Worth, Tex., 1996.

<sup>41</sup> Scott Russell Sanders, "Lessons from the Land Institute," *Audubon*, March–April 1999, pp. 75–79. As of April 13, 2007: <http://magazine.audubon.org/landinstitute.html>.

- production of seeds with favorable flavor qualities
- production of easily threshed seeds
- manageable seed size
- synchronous seed maturity
- resistance to shattering
- strong nonlodging seed stalks
- seedheads held above the level of the foliage
- drydown of seed stalks at maturity
- high potential for mechanical harvest
- vigorous perennial growth.<sup>42</sup>

These characteristics must also be evaluated in succeeding years (the yield usually drops after the first year) and, more important, in connection with other plants in the polyculture (not only which plants, but also the percentages of each and their configurations). Further, any kind of machine harvesting will be a challenge in a reengineered prairie. Also, natural prairies renew themselves after prairie fires—not completely desirable events for engineered *or* natural prairies in the modern world.<sup>43</sup> The pure intellectual and experimental challenges are immense, but the potential is clearly promising, and the rewards are possibly revolutionary.

The greater challenge is making sure that the intellectual and experimental work gets done. Much of agricultural research goes on at large agricultural businesses, such as machinery manufacturers and seed, fertilizer, herbicide, and pesticide producers. None of these, however, is likely to see much economic promise in researching perennial polyculture farming. Even if agricultural businesses were to see some promise for developed countries, there would be less incentive for addressing the individual challenges produced by different conditions in developing countries. As one author said of biotechnology and subsistence agriculture:

Despite the existence of genetic options, we have yet to realize the promise of biotechnology to meet the needs of low-income families in the developing world. There are two main reasons why we have not realized this promise. First, the public sector has traditionally carried out crop development for low-income families, and the private sector lacks the incentives to invest in those biotechnologies that have emerged in crops for low-income families. Second, agricultural research in the public sector has been declining over the years; thus, little investment has gone into developing crops for low-income families.<sup>44</sup>

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<sup>42</sup> P. Wagoner and A. Schauer, "Intermediate Wheatgrass as a Perennial Grain Crop," in J. Janick and J. E. Simon, eds., *Advances in New Crops: Proceeding of the First National Symposium New Crops: Research, Development, Economics*, Timber Press, Portland, Ore., 1990, pp. 143–145. As of April 13, 2007: <http://www.hort.purdue.edu/newcrop/proceedings1990/v1-143.html>.

<sup>43</sup> However, even here, such issues could be addressed by controlled burns—a technique commonly used in forest management across the United States.

<sup>44</sup> Calestous Juma, "Biotechnology in a Globalizing World: The Coevolution of Technology and Social Institutions," *Bioscience*, Vol. 55, No. 3, March 2005, p. 7.

Perennial polyculture agriculture, then, is likely to be an “orphan” concept in the current agricultural world. Even in a world that is paying much more attention to sustainability, agricultural research funding is likely to be spent (at least at first) on trying to reengineer Green Revolution technologies to reduce their negative environmental effects. Therefore, even governmental policies in favor of sustainable agriculture are likely to be approached by trying to make current annual, monoculture agriculture more sustainable.

If this seems unduly pessimistic, there are some positive signs for perennial polycultures and some opportunities to continue research on them—particularly in developing countries where their promise is greatest. Foremost among the positive signs is a significant increase in attention being paid to agriculture in the development community. According to one source:

It is increasing agricultural productivity that has allowed poor countries to get on to trajectories of development that lead to growth and well-being. This is especially true in labor-intensive, small-scale agriculture, with its strong links to growth in other areas. No country has ever successfully reduced poverty through agriculture alone, but almost none have achieved it without first increasing agricultural productivity.<sup>45</sup>

The UN Millennium Development Goals have brought an increased emphasis on poverty reduction, causing the focus to turn to agriculture as an important means of doing so. This focus has spawned such efforts as the Millennium Villages project from Columbia University’s Earth Institute.<sup>46</sup> In that project, agriculture experts, using primarily an annual monoculture approach, are introducing techniques in a few African villages that are dramatically increasing the agricultural production of the villages as part of a wider approach to poverty reduction.

More important, China is a good contemporary example of a developing country that has jumpstarted its economy and lifted more than 400 million people out of poverty since 1981<sup>47</sup> by, among other things, increasing the productivity of its subsistence farmers. After Mao Zedong died, there were three main schools of thought on how to move China forward. Deng Xiaoping led the reform school that eventually won the political battle. In agriculture, his reforms first allowed villages and then individuals to have control over the disposal of above-quota farm output. This encouraged farmers to increase food production and sell anything they produced above their quotas—increasing farm incomes. This reform alone had a significant effect not only on the country’s food production, but on the economy, which has been growing at historically unprecedented rates.

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<sup>45</sup> Calestous Juma, ed., *Going for Growth: Science, Technology and Innovation in Africa*, The Smith Institute, London, 2005, p. 75. As of April 13, 2007: [http://bcsia.ksg.harvard.edu/BCSIA\\_content/documents/GoingforGrowth\\_AMENDEDFINAL.pdf](http://bcsia.ksg.harvard.edu/BCSIA_content/documents/GoingforGrowth_AMENDEDFINAL.pdf).

<sup>46</sup> More details can be found at Columbia University’s Earth Institute Web site for the Millennium Villages. As of April 13, 2007: <http://www.earthinstitute.columbia.edu/mvp/>.

<sup>47</sup> S. Chen and M. Ravallion, “How Have the World’s Poorest Fared Since the Early 1980s?” Policy Research Working Paper WPS33412, World Bank, Washington, D.C., 2004. As of April 13, 2007: [http://www.worldbank.org/research/povmonitor/MartinPapers/How\\_have\\_the\\_poorest\\_fared\\_since\\_the\\_early\\_1980s.pdf](http://www.worldbank.org/research/povmonitor/MartinPapers/How_have_the_poorest_fared_since_the_early_1980s.pdf).

The connection between agriculture and poverty reduction has, for the most part, concentrated on industrial agriculture, but it opens opportunities to pay more attention to perennials. Beyond the increased emphasis on agriculture, in Africa in particular, institutional, social, and technological advances work in favor of including perennial polycultures in improving agriculture (and reducing poverty).

In the institutional realm, perhaps the most important advance has been the creation of the Comprehensive Africa Agriculture Development Programme (CAADP) under the New Partnership for Africa's Development (NEPAD) strategic framework. NEPAD arose from a mandate given to the five initiating heads of state (in Algeria, Egypt, Nigeria, Senegal, and South Africa) by the Organisation of African Unity to develop an integrated socioeconomic development framework for Africa.<sup>48</sup> The CAADP was prepared by the FAO in cooperation with the NEPAD steering committee and presented to and endorsed by African Ministers of Agriculture in June 2002. The CAADP calls for four areas of primary action:

- Extend the area under sustainable land management and reliable water control systems.
- Improve rural infrastructure and trade-related capacities for market access.
- Increase food supply and reduce hunger.
- Promote agricultural research, technology dissemination, and adoption.

While the CAADP does not specifically call for research on perennial polycultures, many of its goals could be advanced by perennial polycultures. For example, the CAADP notes that:

Soil degradation indicated by nutrient depletion and loss of organic matter, resulting from erosion and extraction and loss in excess of return, has direct negative influence on agricultural productivity. This may be the single most important constraint to food security in Africa.<sup>49</sup>

In the social realm, besides the increased emphasis on poverty reduction that is fueling interest in agriculture in general, an increasing emphasis on sustainability also favors perennial polycultures. There are varying definitions of sustainability, but most include reversing environmental damage. Industrial agriculture is an important contributing factor to environmental damage, and perennial polycultures could help reverse that damage. The CAADP has an entire section on the importance of ecological sustainability, and in 2006 the FAO produced a companion piece to the CAADP integrating livestock, forestry, and fisheries into the CAADP. One of the UN Millennium Development Goals is to ensure environmental sustainability, with a specific target to reverse loss of environmental resources. Continuing concern for sus-

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<sup>48</sup> See the NEPAD Web site for additional details. As of April 13, 2007: <http://www.nepad.org/>.

<sup>49</sup> Food and Agriculture Organization of the United Nations, *Comprehensive Africa Agriculture Development Programme*, FAO Regional Conference for Africa (ARC), ARC/FKI/02/2-NEPAD, Rome, Italy, 2002. See also, "Road to Sustainability," in Chapter 5, Agricultural Research, Technology Dissemination and Adoption. As of April 13, 2007: [http://www.fao.org/DOCREP/005/Y6831E/y6831e-06.htm#P1206\\_281794](http://www.fao.org/DOCREP/005/Y6831E/y6831e-06.htm#P1206_281794).

tainability and for reversing environmental damage, then, could drive interest in perennial polycultures.

Finally, in the technological arena, there are at least two developments that provide impetus for research into perennial polycultures. The first is the revolutionary advances in biotechnology that enable understanding and altering the behavior of plants and animals. In the early stages of the biotechnological age, we do not yet know what will be possible, but making perennials out of annual species; increasing the abilities of plants to produce human food; and altering the abilities of plants to provide their own fertilizer, herbicides, pesticides, etc. appear well within our reach. Some aspects of each have already been demonstrated. As mentioned earlier, biotechnology is more likely to be applied to improve the characteristics of annual monocultures before it is applied in the area of perennial polycultures, but the tools exist to do either.

The other area in technological development, which specifically affects Africa, has been the cataloging of the “lost crops” of Africa. The National Research Council undertook studies to assess the state of knowledge, the promise, and the limitations of little-known African grains, fruits, and vegetables that have potential importance as food and cash crops in Africa and possibly elsewhere. The result will ultimately be three reports—one on grains, one on vegetables, and one on fruits.<sup>50</sup> The volume on grains has already appeared and identifies several grains that are native to Africa (such as sorghum, millet, and African rice) that, for a variety of reasons, have been neglected since colonial times in favor of maize, (imported) rice, and wheat. These varieties have characteristics that are very promising. As the report states:

Already, sorghum is a booming new food crop in Central America. Pearl millet is showing such utility that it is probably the most promising new crop for the United States. Nutritionists in a dozen or more countries see finger millet and some sorghums as the key—finally—to solving Africa’s malnutrition problem. Food technologists are finding vast new possibilities in processes that can open up vibrant consumer markets for new and tasty products made from Africa’s own grains. And engineers are showing how the old grains can be produced and processed locally without the spirit-crushing drudgery that raises the resentment of millions who have to grind grain every day.<sup>51</sup>

Again, these varieties are generally seen in terms of annual monocultures, but there is no reason to believe at this point that some of those plants could not produce similar results as part of perennial polycultures. The more important point is that, through these studies, the National Research Council has already done a culling of Africa’s 2,000-plus plant species to identify those that might best be used to improve on the agricultural species in common use

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<sup>50</sup> Board on Science and Technology for International Development, Office of International Affairs, National Research Council, ed., *Lost Crops of Africa: Volume I, Grains*, National Research Council, National Academy Press, Washington, D.C., 1996. As of April 13, 2007: <http://www.nap.edu/catalog/2305.html>. *Lost Crops of Africa: Volume II, Vegetables*, 2006. As of April 13, 2007: <http://fermat.nap.edu/books/0309103339/html>. The third volume on fruits is in preparation.

<sup>51</sup> *Lost Crops of Africa: Volume I: Grains*, 1996, p. 2.

today in Africa. In the search for appropriate perennial polyculture species, these studies are invaluable assets.

Overall, then, while there is a good deal of work to be done to develop the promise of perennial polycultures, there is reason to believe that that promise is real, that it is particularly salient with respect to Africa—the region that could most use the promise of perennial polycultures—and that there are many elements already in place to make that promise a reality. Only lacking are greater recognition of the role that perennials could play and the will to include them in the future of agriculture.